Refined Source Terms in WAVEWATCH III with Wave Breaking and Sea Spray Forecasts

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Award Number: N00014-10-1-0390

LONG-TERM GOALS

Several U.S. Federal Agencies operate wind wave prediction models for a variety of mission specific purposes. Much of the basic science contained in the physics core of these models is over a decade old, and incorporating recent research advances over the last decade will significantly upgrade the model physics. A major goal is to produce a refined set of source and sink terms for the wind input, dissipation and breaking, nonlinear wave-wave interaction, bottom friction, wave-mud interaction, wave-current interaction as well as sea spray flux. These should perform demonstrably better across a range of environments and conditions than existing packages and include a seamless transition from deep to shallow water outside the surf zone. After careful testing within a comprehensive suite of test bed cases, these refined source terms will be incorporated into the prediction systems operated by these agencies and by the broader wave modelling community.

OBJECTIVES

Our aim to improve the accuracy of ocean wave forecasts over a wide dynamic range of wind speeds out to hurricane conditions, contributing a dissipation source function that adds explicit wave breaking statistics for the wind sea to the forecast products. Allied aims are to effectively decouple swell systems from the wind sea and to provide a framework that allows full coupling to the associated atmospheric and ocean circulation models. As part of this project we aim to refine the parameterization of air-sea and upper ocean fluxes, including wind input and sea spray as well as dissipation, and hence improve marine weather forecasts, particularly in severe conditions.

APPROACH

We have continued using our refined version of the threshold-based spectral dissipation rate source term S_{ds} introduced by Alves and Banner (2003), as described recently in detail by Banner and Morison (2010). This replaces the original Komen-Hasselmann integral formulation for S_{ds} presently used in most operational models. The performance of this updated source term was investigated in conjunction with a modified Janssen (1991) wind input source term and the ‘exact’ form of the nonlinear source term S_{nl} (Tracy and Resio, 1982) over a very wide range of wind speeds using a broad computational bandwidth for the wave spectrum. This avoided the known spurious effects arising in faster approximate versions for this source term.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2011**	2. REPORT TYPE	3. DATES COVERED **00-00-2011 to 00-00-2011**

4. TITLE AND SUBTITLE **Refined Source Terms in WAVEWATCH III with Wave Breaking and Sea Spray Forecasts**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **The University of New South Wales,School of Mathematics and Statistics,Sydney 2052, Australia,**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

A significant issue is the additional wind stress component due to the separated air flow over breaking waves. Our methodology produces breaking wave stress parameterizations linked to computed breaking wave properties, and indicates that this additional wind stress component can be an appreciable fraction of the total wind stress depending on the wind speed and wave age conditions, consistent with observations of Banner (1990). In hurricanes, our calculations suggest it is around one third of the non-breaking wave stress.

Detailed comparisons have already been made with growing wind sea results from the ONR FAIRS open ocean data set (e.g. Edson et al., 2004) gathered from FLIP in 2000. Here, breaking wave observations that were made along with measurements of wind stress, wave height and water-side dissipation rate. Our model results closely reproduced these observations, including the breaking wave properties. We have also tested our model framework over the wind speed range of 6-100 m/s and found the model behaved stably and produced plausible results for both wave and sea surface drag coefficient behaviour.

We have continued to investigate the performance of our model framework, by seeking to reproduce a period in which the wind relaxed from 14 m/s to 9 m/s over a period of 12 hours. During this period, there was a strong attenuation of the wind sea. Forecasting such wave energy decay episodes turns out to be an area of great interest and challenge, as it is a situation that occurs quite commonly, yet it is not well forecast by present operational models. Historically, such relaxation tests have seldom been used to routinely assess wave model performance.

We are also presently engaged in transitioning our model framework to the WaveWatch III environment, using the Exact NL option for the nonlinear source term in our model refinement.

WORK COMPLETED

During FY11 we have further refined our source terms. As part of our modelling effort, we have investigated the performance of our refined dissipation and input source terms during observed increasing and decreasing wind events. For the nonlinear spectral transfers, we used Exact NL. We have focused on: (i) optimizing the source terms to evolve stably over the dynamic range of 6-100 m/s winds; (ii) improving the low wind performance in relation to the drag coefficient; (iii) validating the model against several ocean data sets containing wind relaxation events, including our RaDyO ONR field experiments, and the FAIRS experiment. Initially we have been assuming the wave field is duration-limited, i.e. no net propagation effects. This assumption is being relaxed as we transition our model framework into the WaveWatch III environment.

RESULTS

The duration limit growth curves for the non-dimensional wave energy and peak frequency for wind speeds from 6-100 m/s are shown in Figure 1. They are seen to track closely along the standard growth curves. The spectral shapes, directional spreading widths and other properties of interest all conform to available data. The ability of the model to reproduce observed drag coefficients from the various wind stress contributions (wind input to the waves, additional input to breaking waves, tangential stress input) over an extremely wide range of wind speeds and without any limiters is seen in Figure 2. Often the higher wind speed cases observed are associated with shorter durations, hence their drag coefficients are further elevated in comparison with observed drag coefficients at lower wind speeds, where the seas are often older.

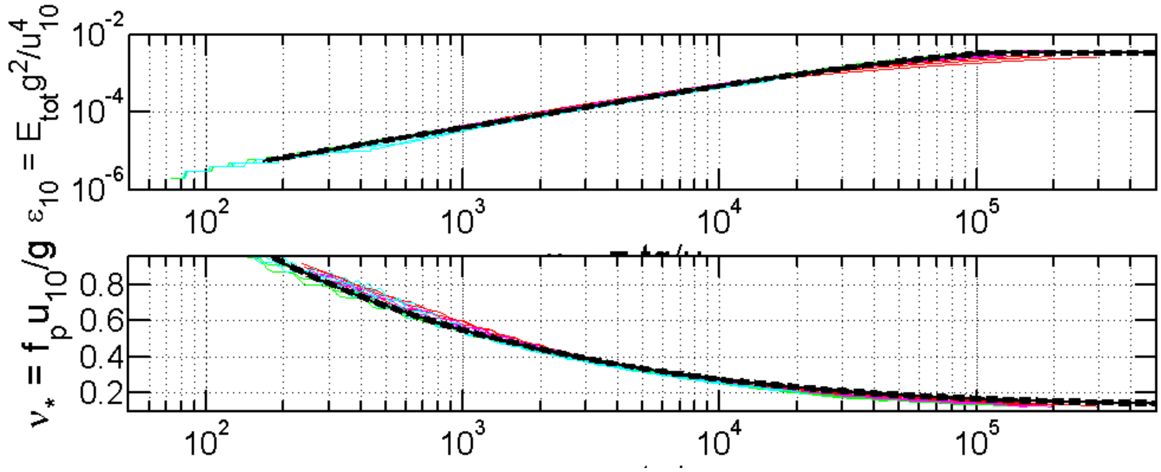

Figure 1. Duration limit growth curves for the non-dimensional wave energy and peak frequency for wind speeds from 6-100 m/s. The heavy dashed line is the best fit to the observed data.

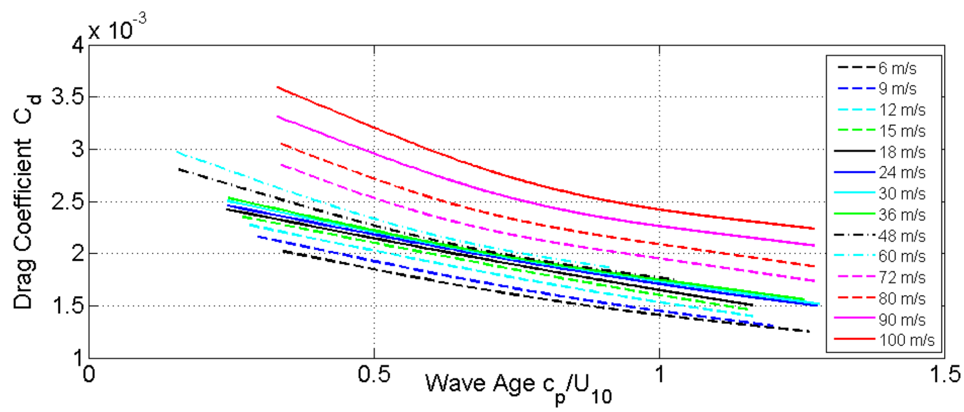

Figure 2. Drag coefficient C_d computed from the modeled wave-coherent wind stress, the tangential viscous stress and the additional wind stress due to separation over breaking waves, as a function of the wave age c_p/U_{10}.

In Figure 3 we show an application of our refined source terms. This is a duration-limited calculation of the evolution of the measured and modeled significant wave height for the period YearDay 272-278 of 2000 during the FAIRS experiment from RP FLIP in the open ocean off Monterey. Allowing for a slight mismatch in the starting condition, it is seen that the model tracks the growth phase well, apart from slightly underestimating the energy at YearDay 273.5. There is a small overshoot between YerDay 274.5 to 275.5. Thereafter it is seen that in response to the subsequent wind relaxation from 14 m/s down to 9 m/s, the modeled SWH falls at a much slower rate than was measured, but reaches the same level around YearDay 277. Clearly the model does not reproduce optimally this phase of the observed evolution. This is an area which we are addressing presently with a WW3 implementation of our source terms that includes the spatial and temporal variability of the wind field, advective effects, ambient currents, presence of distant swells, etc. From our progress to date, it is evident that current source terms experience difficulty accurately forecasting relaxing wind situations.

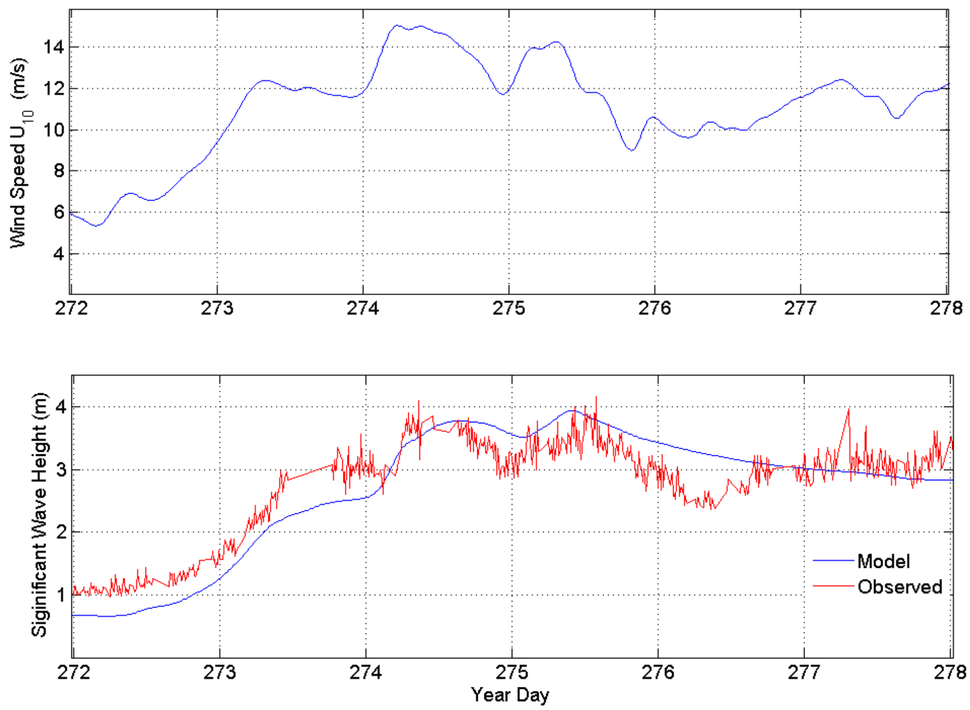

Figure 3. Evolution of the significant wave height during the FAIRS experiment. The upper panel shows the 10m wind speed as a function of the YearDay. The lower panel shows the corresponding observed and modeled significant wave height evolution.

IMPACTS and APPLICATIONS

This effort will contribute significantly to the major NOPP goal of upgrading the model physics for wind generated ocean waves, the near-surface winds and upper ocean circulation in the WaveWatch III model environment. The upgraded WaveWatch III model code will be distributed to various Federal agencies for incorporation in their mission-specific systems. The major impact will be more accurate and comprehensive sea state and marine meteorological forecasts from the next generation of operational sea state models.

National Security

Distribution of the upgraded WaveWatch III to the US Navy and Army Corps of Engineers (USACE) should result in improved environmental forecasts of open ocean and coastal zone waves, winds and currents and increase the reliability and safety of naval and USACE operations.

Economic Development

Implementation of the upgraded WaveWatch III by the National Weather Service (NWS), NOAA and other agencies in Department of Commerce should see economic benefits accruing from: improved design criteria for coastal and offshore structures; increased safety during operations; more accurate weather forecasts, especially associated with hurricanes and coastal storms.

Quality of Life

Benefits will arise through improvements in NWS public weather and coastal maritime forecasts, evacuation associated with hurricanes and severe coastal storms, as well as infrastructure protection (e.g. foreshore erosion, coastal property damage and loss).

Science Education and Communication

The improvements in understanding of the physical processes (dynamics and associated fluxes between atmosphere and ocean) derived from this project will be published in the mainstream literature for public dissemination.

TRANSITIONS

This effort will contribute significantly to the major NOPP goal of validating and transitioning the new model physics for wind generated ocean waves, the near-surface winds and upper ocean circulation into the WaveWatch III model environment. The upgraded modeling environment will be distributed to various Federal agencies for incorporation in their mission-specific systems.

National Security

Improved environmental forecasts of open ocean and coastal zone waves, winds and currents should increase the efficiency and safety of Naval operations and Army Corps of Engineers projects.

Economic Development

Utilization of the upgraded modeling systems will lead to improved design criteria and practice for coastal and offshore structures and safety, as well as improved weather forecasts, especially during hurricanes and storms.

Quality of Life

There is a premium on the reliability of public weather and maritime forecasts, for evacuation announcements, infrastructure protection as well as routine day-to-day lifestyle decisions. The envisaged model improvements should enhance present capabilities.

Science Education and Communication

Results from the improved understanding of physical processes (dynamics and associated fluxes between atmosphere and ocean) obtained during this project will be published in the open literature for broad dissemination.

REFERENCES

Alves, J.H and M.L. Banner (2003) Performance of a saturation-based dissipation source term for wind wave spectral modeling. J. Phys. Oceanogr. 33, 1274-1298.

Banner, M.L. and R.P. Morison (2010) Refined source terms in wind wave models with explicit wave breaking prediction. Part I: Model framework and validation against field data. Ocean Modell., doi:10.1016/j.ocemod.2010.01.002.

Tracy, B.A. and D.T. Resio (1982) Theory and calculation of the nonlinear energy transfer between sea waves in deep water, WIS Rept 11, US Army Engineers Waterway Experiment Station.

Edson, J.B., C.J. Zappa, J.A. Ware, W.R. McGillis and J.E. Hare (2002) Scalar flux profile relationships over the open ocean, J. Geophys., 109, C08S09, doi:10.1029/2003JC001960.